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13. ABSTRACT ***(Maximum 200 Words)***

This concept exploration proposal seeks to determine if a novel x-ray technique called diffraction enhanced imaging, which provides dramatic gains in contrast over conventional radiography, can be used to identify microdamage in bone non-invasively. This technique has been used successfully in soft tissues, including recent studies by our group to detect damage in articular cartilage. Here, we plan to extend our work to studies relevant to microdamage accumulation and repair in bone. Interest in microdamage in bone comes in part from its likely role in the etiology of stress fractures. In addition, microdamage accumulation may contribute to osteoporotic fractures and loosening of dental or orthopedic implants. Our working hypothesis is that microdamage in bone can be detected non-invasively by diffraction enhanced imaging because this imaging modality expands the ability of x-rays to record refraction and scatter rejection (extinction) as well as absorption. No matter the spatial scale of the fracture feature, diffraction enhanced imaging has a contrast mechanism suited to make the feature visible. We have performed two sets of experiments to address Specific Aim 1, which focuses on using machined bone samples to determine if induced microdamage can be detected non-invasively. The results suggest that this may be possible and we are currently designing and carrying out an additional experiment to confirm these observations.

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INTRODUCTION

This concept exploration proposal seeks to determine if a novel x-ray technique called diffraction enhanced imaging, which provides dramatic gains in contrast over conventional radiography, can be used to identify microdamage in bone non-invasively. This technique has been used successfully in soft tissues, including recent studies by our group to detect damage in articular cartilage. Here, we plan to extend our work to studies relevant to microdamage accumulation and repair in bone. Interest in microdamage in bone comes in part from its likely role in the etiology of stress fractures. In addition, microdamage accumulation may contribute to osteoporotic fractures and loosening of dental or orthopedic implants. Our working hypothesis is that microdamage in bone can be detected non-invasively by diffraction enhanced imaging because this imaging modality expands the ability of x-rays to record refraction and scatter rejection (extinction) as well as absorption. No matter the spatial scale of the fracture feature, diffraction enhanced imaging has a contrast mechanism suited to make the feature visible. Specific studies to determine the optimum imaging parameters and to compare diffraction enhanced images of machined samples and intact bones before and after induction of mechanical testing have been designed to address the hypothesis.

BODY

We have focused on Task 2 because it is the most important part of the proposed work. The reviewers of the grant felt that Task 1 was not important. In addition, we have modified the experimental design to accommodate the practicality of access to the key resource in the project -- the National Synchrotron Light Source (NSLS) at Brookehaven National Laboratory and have eliminated the need to subject the specimens to freeze-thaw cycles (Task 1).

Experiment 1a was designed to determine if "large" defects could be imaged by DEI. In this experiment, two machined bovine cortical bone samples were drilled with different diameter drills and then a "conventional" synchrotron radiograph and diffraction enhanced images at three places along the rocking curve (0, -1 and +1) were collected. The images were collected with the samples in a vertical position and with them in a horizontal position at 30 KeV and 40 KeV.

Experiment 1b was carried out to determine if a non-displaced fracture could be imaged. In this experiment, two machined bovine cortical bone samples were bent until they broke, the fragments were fit back together and the same set of images were made as in Experiment 1a.

Sample images for Experiments 1a and 1b are shown in Figure 1. While the induced breaks (2 left samples) and drill holes (2 right samples) are visible in the radiograph (panel A), considerably more detail can be appreciated in the diffraction enhanced images (panels B,C and D). In particular, the ability of the new technique to highlight surface phenomena is evident. Some of the surface structure is certainly internal (e.g., in panel C it appears that the surface created by the drill can actually be visualized) and some of the surface detail may come from the machined surfaces of the samples.

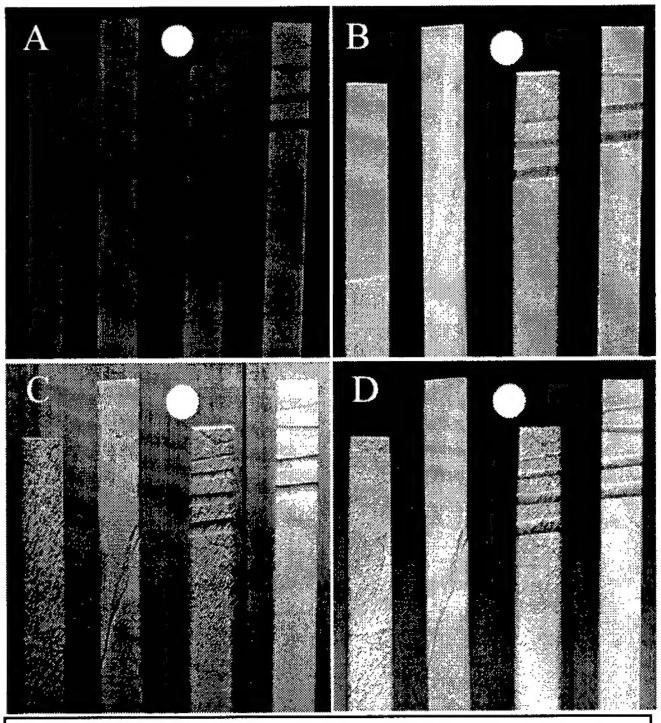

Figure 1. Sample images obtained for Experiments 1a and 1b. A) Synchrotron radiograph, B) Diffraction enhanced image at the top of the rocking curve, C) Diffraction enhanced image at -1 on the rocking curve, D) Diffraction enhanced image at +1 on the rocking curve.

Experiment 1c was carried out to determine if microdamage could be detected. In this experiment two machined bovine cortical bone samples were imaged before and after inducing microdamage. The microdamage was induced by fatigue loading the samples until there was approximately a 20% reduction in the structural stiffness of the specimen. Figure 2 shows some of the results from Experiment 1c. The most noticeable finding was that even though it was difficult to discern a difference in the images from the sample before induction of microdamage (unstressed) and after induction of microdamage (stressed) by visual inspection of the images (panel A), the analysis of the rocking curves indicated that the width of the rocking curve was greater for the unstressed as opposed to the stressed condition. Thus, it is possible that a microdamage "signature" may be present that can be detected by DEI.

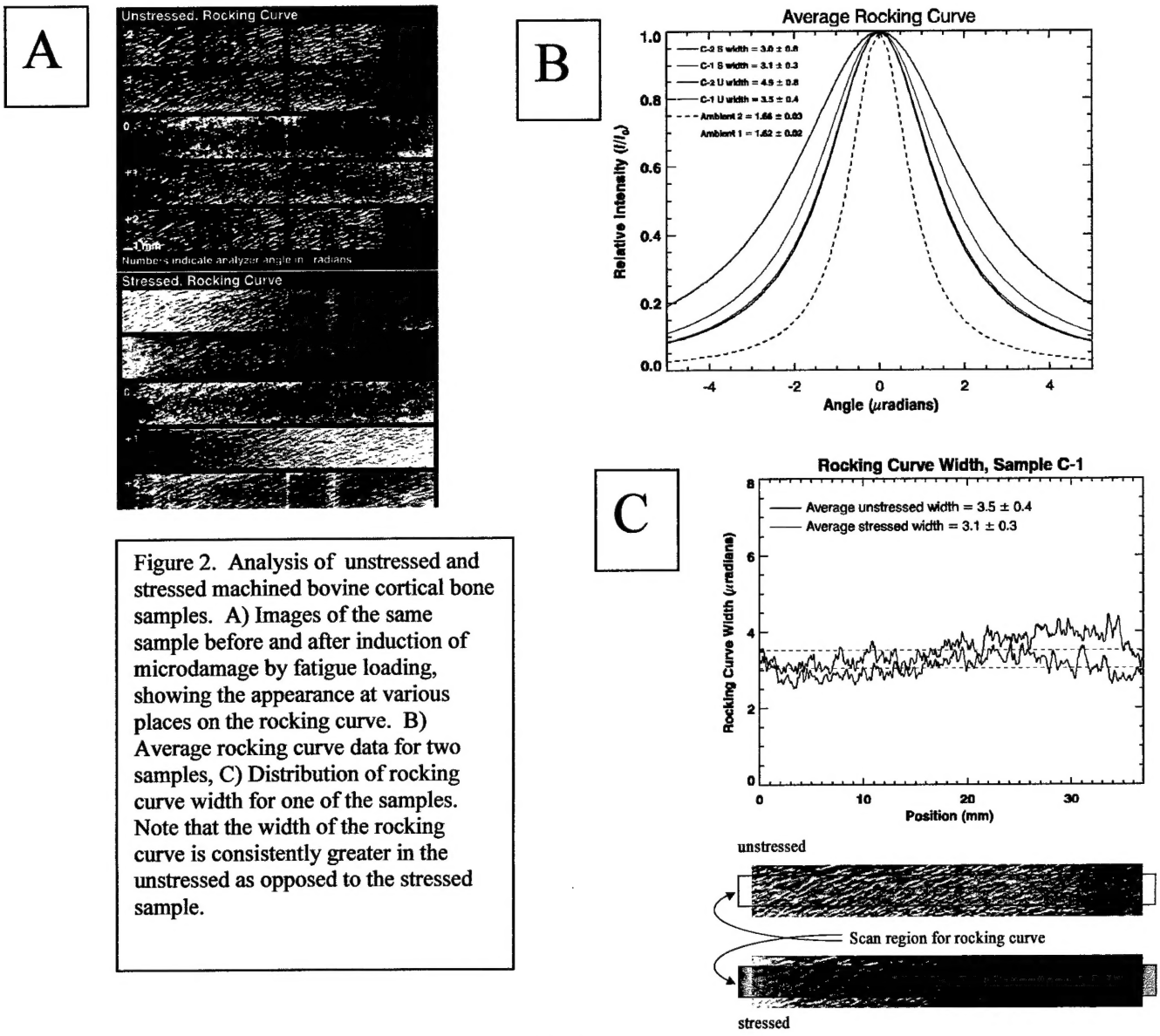

Figure 2. Analysis of unstressed and stressed machined bovine cortical bone samples. A) Images of the same sample before and after induction of microdamage by fatigue loading, showing the appearance at various places on the rocking curve. B) Average rocking curve data for two samples, C) Distribution of rocking curve width for one of the samples. Note that the width of the rocking curve is consistently greater in the unstressed as opposed to the stressed sample.

Experiment 2a attempted to determine if different levels of microdamage could be detected. In this experiment, we attempted to induce different levels of microdamage by using different criteria for the fatigue loading protocol (e.g., fatigue loading until the structural stiffness was reduced by 40% as opposed to 20%). We found that this graded loading above 20% was not possible because the specimens broke once the structural stiffness reduction exceeded 20%. Conversations with colleagues who have fatigue loaded bone for other purposes confirmed that it is very difficult to reduce the structural stiffness by more than 20%. We are continuing to analyze the data from Experiment 2a and are finding consistent differences in the rocking curve width associated with whether or not the sample had been fatigue loaded. We have also begun to calculate the fractal dimension of images from this experiment and the preliminary analyses suggests that there may be consistent differences between unstressed and stressed samples. This may prove very interesting because fractal analysis provides information about the structures in an image.

KEY RESEARCH ACCOMPLISHMENTS

- Confirmation that Diffraction Enhanced Imaging highlights surface (external and internal) features.
- It seems likely that microdamage can be detected by comparing the "rocking curve" widths of samples before and after induction of damage.
- It may be possible that the fractal dimension of the generated images can also be used to detect the presence of microdamage.

REPORTABLE OUTCOMES

- no manuscripts or abstracts, although we do plan to begin submitting abstracts and manuscripts based on the data obtained in this concept exploration grant.
- DJ Connor, a graduate student of the director of the lead investigator at the North Carolina State University site, is being supported by this grant.

CONCLUSIONS

If studies during the second year of this two-year concept exploration grant confirm that microdamage is detectable non-invasively under controlled laboratory conditions, we will be motivated to apply the technology in a more clinical setting. The challenge will be to identify microdamage against a background of normal skeletal variation. One possible approach would be to determine the level of this background variation and whether or not microdamage can be positively identified. It may turn out that it is only possible to assign a risk factor or suspicion of microdamage based on DEI imaging, much like bone densitometry is used to assess risk of developing a fracture by characterizing the bone density.

REFERENCES

none